SO_X RECLAIM STUDY

FINAL REPORT

MODULE 3-E: WET/DRY SCRUBBING TECHNOLOGY FOR CEMENT KILNS AND COAL-FIRED FLUIDIZED BED BOILER

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I. EXECUTIVE SUMMARY

ETS, INC was commissioned to conduct an engineering evaluation and cost analysis assessment for wet/dry scrubbers to control SO_2 emissions from two cement kilns and a coal-fired fluidized bed boiler located at the California Portland Cement Company (CPCC) facility in Colton, California. Outputs of the program include an evaluation of existing commercially available control technologies, starting with the most effective control technology, recommendations to SCAQMD on various technologies that could potentially be used to achieve additional emission reductions, various concentration targets that could be achieved with each technology, the estimated emission reductions, the multimedia impacts, energy impacts of the technologies, and the cost-effectiveness associated with the control technology.

ETS' John McKenna and Jeff Smith visited the site on September 18, 2008. Others at the site meeting included Minh Pham (SCAQMD), Gary Thornberry, Rick Jacobs, and Julia Lakes (all of CPCC). The purpose of the visit was to assess the performance of the facilities existing SO_2 emission control equipment and available space to install future control equipment on two cement kilns and a coal-fired fluidized bed boiler (COGEN). With the exception of moving some existing coal piles, there appears to be no limitation on available space for prospective equipment for additional SO_2 control on the two cement kilns. If necessary, the existing baghouses could be considered for technology approaches (such as spray drying) requiring a filter collector after the reaction vessel. In this scenario the baghouse would serve the dual purpose of particulate control and the dust cake (on the bags) would provide an additional site for the reaction of the reagent with the SO_x. As in the kiln case, there appears to be no limited space for prospective equipment for additional SO_2 removal on the COGEN. In addition, if the physical integrity of the existing pulse jet baghouse is sound, it could probably be utilized in conjunction with some of the dry or semi-dry scrubbing technologies. This could be accomplished by replacing any malfunctioning components such as valves, timers, dampers, etc., and replacing the existing bag set with high efficiency PTFE membrane bags.

An additional objective of the visit was to obtain emission and operational information pertinent to the successful fulfillment of the overall program objectives. Information supplied by the plant was reviewed and analyzed. From this exercise a gas stream definition (inlet definition) was developed. This information along with a description of the processes was sent to prospective flue gas desulfurization (FGD) technology suppliers in a request for budgetary proposal (RFP) package. Sixteen vendors were contacted and of these, three responded with a quotation. The vendor responses were reviewed for technical approach and descriptive clarity, equipment capital cost, shipping cost or equipment weights, and expected usage rates for reactant material and utilities. Installation and operating costs were then developed for each technology approach and compared in spreadsheet format. A report detailing the status of project activities as of October 15, 2008 was submitted to SCAQMD on that date.

ETS has conducted a top down analysis of alternative commercially feasible control technologies for the control of SO_x emissions from the cement plant. This analysis considered the technology which was found to be the most effective in terms of sulfur dioxide removal and which can potentially be installed or retrofitted at CPCC. In the case of the two kilns, three vendors (Manufacturer A, Manufacturer B, and Manufacturer C) submitted quotes and performance claims. Given the higher removal efficiency (95%), the Manufacturer B $CaCO_3$ Scrubber was selected as BARCT for the kilns.

Similarly top down analysis was done for the coal-fired fluidized bed boiler emission control at the cement plant. Four vendors (Manufacturer A, Manufacturer B, Manufacturer C, and Manufacturer D) submitted quotes and performance claims. Given the 95% removal efficiency, both the Manufacturer D Venturi Reactor & the Manufacturer B $CaCO_3$ Scrubber can be considered BARCT for the coal-fired fluidized bed boiler.

Cost-effectiveness determinations were executed for the BARCT cases and a summary of the results are provided in the following table.

Summary of Recommendations

Equipment	BARCT Level	BARCT Emission Level	Emission Reductions	Cost Effectiveness
Kilns	95% control (≤2 ppmv)	0.03 lbs SO_x/ton clinker	0.25 tpd SO_x	$18.9 K/ton SOx
Coal-Fired Boiler	95% control (≤5 ppmv)	NA	0.36 tpd SO_x	$ 3.8 K/ton SOx

Note: Baseline SO_x emissions used in calculations were from 2005 (SCAQMD database for the period from January 2005 – December 2005)

The following document is to be considered as the final report; it provides commentary on all tasks that have been completed, problems encountered and solutions, explanations of technical and economic analysis conducted, as well as the results and conclusions of these exercises.

II. FACILITY & EMISSION PROFILE

II. A. General Facility & Equipment Description

The facility operates two "long dry process" rotary kilns; each kiln is about 13 ft. bottling out to 15 ft. in diameter by 490 ft long. The operation for each kiln is as follows; raw materials are fed into the upper end of the kiln while fuels are burned at the lower end. The combustion fuel is a combination of coal, coke, oil, natural gas, and used tires. Raw feed material consists of limestone, silica, and clay. As the kiln rotates, the raw materials and combustion gases flow in a countercurrent direction. The combustion gases are vented through a dust separator, a waste heat boiler, and an economizer. The gases are then directed to a reverse gas baghouse before exiting through the exhaust stack. The material captured in the baghouse can either be reused as feed or targeted for waste disposal. A simple line diagram typical of each kiln operation is attached as Figure 1.

The facility also has a 15 MW coal-fired fluidized bed boiler that reportedly has not been operated since March 2002. It is uncertain when and if the boiler will be used as its future operation is dependent on energy costs and fuel source availability. Flue gases are directed from the boiler, through a mechanical dust collector, economizer, air preheater, and pulse jet baghouse before exiting through a stack to atmosphere. A line diagram of the COGEN system is presented in Figure 2.

II. B. Current Emission Profiles in 2005 and 2008

Continuous emissions monitoring (CEMs) data was provided for both kilns for years 2005 and 2008 (January through September). In addition, similar CEMs data for the COGEN boiler was provided for 2001. Both cement kiln and COGEN CEMS data were supplied in spreadsheet form with one row per 15-minute or 1-hour average of all recorded system variables. The total number or rows ranged from about 6,000 for the COGEN unit to about 19,000 for one of the kilns. Examination of the data showed several characteristics that required treatment before estimating statistics. When a unit was not operating, was operating at low temperature, or was sending improper data, spreadsheet cells could register blanks, zeros, or "null." In some cases the CEMS recorded strings of very low or very high repeated numbers, and in other cases a single high value significantly above the second highest value. For statistics about all of the process variables, all cells with blanks, zeros, or "null" were ignored for estimation of count, maximum value, minimum value, average (mean), standard deviation, and relative deviation. For direct comparison of NO_X and SO_2, additional data treatment was done: rows with low-value strings were ignored, as were rows not having acceptable values for both NO_X and SO_2. Additional statistics were estimated for this comparison: median, correlation coefficient and its square, skewness, and kurtosis. The information gleaned from this exercise, along with stack testing reports for both processes and other information supplied by the plant was used to develop a set of inlet conditions that were subsequently sent to equipment vendors for the basis of their respective budgetary quotations. Table 1 provides the results of our statistical analysis of the CEMs data for Kilns 1 and 2 as well as those for the COGEN plant. Summaries of the stack gas SO_2 concentration, temperature, and flow rate data gathered throughout the project from various sources for the kilns and COGEN plant are shown in Tables 2, 3, and 4.

III. CONTROL TECHNOLOGY - FEASIBILITY ANALYSIS

III. A. Critique on SCAQMD Preliminary Draft Report

Chapter 9 of the SCAQMD report provides an overview on Portland cement manufacturing at the CPCC facility as well a more detailed explanation of the pyro-processing process employed at the facility. While there is general information on the operation and chemistry of fluid bed boilers, the chapter provides no information on the CPCC facility fluid bed boiler; this is probably because it has not been in service since 2002 and its future use is uncertain. The chapter provides a decent overview of the various SO_2 removal technologies for both industrial boilers and cement kilns. Listed below are specific comments for sections 9.3 and

9.4 dealing with control technologies for coal-fired fluid bed boilers and cement kilns respectively:

9.3 Control Technology for Coal-Fired Fluidized - Bed Boilers
This section appropriately notes that in process control technology is suitable here and that 90% SO_2 removal is possible via the injection of limestone. In addition this section briefly describes the post combustion control of SO_2 via dry and wet scrubbing.

9.4 Control Technology for Cement Kilns
This section provides a brief discussion and a table showing the control efficiency for three types of controls i.e. 1-fuel switching & process alteration, 2- dry scrubbing & 3- wet scrubbing. It does not discuss the performance limitations and relative high scrubber costs considerations when the scrubber inlet is 10 ppm or less. A discussion of reagent direct injection either in the kiln or post kiln is needed here.

III. B. Literature Research on Control Technology

A search was conducted to identify studies and technical presentations and papers relevant to control of SO_2 emissions from cement kilns and industrial coal-fired boilers. Sources for this information included Air Waste Management Association (AWMA), The McIlvaine Company, USEPA, Institute of Clean Air Companies (ICAC), Portland Cement Association (PCA), and Northeast States for Coordinated Air Use Management (NESCAUM), the Internet, and direct communication with personnel contacts. We are not sure how many kilns in North America have SO_2 control equipment installed on the kiln exhaust gas. The Portland Cement Association 2005 report "***Capabilities and Limitations of Available Control Techniques for Mercury Emissions from Cement Kilns"*** stated that in the U.S. there were only two kilns equipped with SO_2 scrubbing and two new kilns with wet scrubbing systems will be constructed in the near future. NESCAUM's "***Assessment of Control Technology Options for Bart-Eligible Sources"*** chapter 4 provides a good description of the cement making process, the available SO_2 control options (process alterations, reagent injection, dry scrubbing and wet scrubbing) and their expected SO_2 removal performance. Capital and operating costs for each generic approach is also provided. This paper also provides similar information on industrial boilers in chapter 3. The December 2007 NESCAUM "***BART Guideline"*** provides a listing of BART eligible cement plants in the NESCAUM region. Listed below is a summary of the technologies cited in the report.

III. C. Discussion of Control Technology and Potential Emissions Reduction

Dry Injection

RMC Pacific process - injects dry Ca $(OH)_2$ at high stoichiometric ratios (40 to 50:1), efficiencies ranging from 55%-65%.

Krupp Polysius Polydesox uses hydrated lime where SOx in the raw feed tends to form pyrites and obtains removal efficiencies up to 85%.

Fuller's De-SoX Cyclone-directs a portion of the pre-calciner outlet flue gases to a series of two cyclones where pyritic sulfur in the kiln feed is decomposed into SO_2. The feed, containing freshly produced lime is discharged into the outlet duct of the second stage (also known as hot meal injection) to obtain 5-30% removal efficiencies.

Lime/Limestone Spray Drying

RMC Pacific Alkaline Slurry Injection - uses hydrated lime and a spray dryer absorber to reduce SOx emissions. The captured sulfur compounds are returned as a portion of the raw material feedstock to the roller mill, which results in no scrubber effluent or sludge disposal. This approach uses high stoichiometric ratios and is limited in application. SOx removal of 55-80% reported, depending on stoichiometry and location of slurry injection.

Enviro-Care Microfine Lime System - This system uses the existing gas conditioning tower to introduce the scrubbing reagent (water suspension of finely pulverized calcium hydroxide). The small size of the lime particles (3-10 microns) allows the particles to dissolve in the water droplets quickly and react with SOx as it is absorbed into the water droplet. The dried lime continues to react with any remaining SOx in the downstream kiln system and particulate control device. Lime injection rate is optimized through a feedback control loop from an SO2 monitor. EnviroCare claims greater than 90% removal efficiencies.

Wet Scrubbing Systems

Monsanto EnviroChem DynaWave- a "reverse jet" scrubber that can simultaneously accomplish hot gas quenching, particulate removal, and acid gas absorption. The reverse jet is an annular orifice scrubber one to three large bore nozzles through which a large volume of scrubbing liquid is injected counter to the gas flow to create a froth zone. In this turbulent zone the gas absorption and particulate collection occurs. The system is located downstream of the particulate control device. A single stage DynaWave scrubber has reported 90% removal. Monsanto claims that multiple units installed in series can achieve up to 99.9% efficiency. MECS, Inc. indicated that they could remove 99+% of SO_2, down to a lower limit of 10-15 ppm, using lime, limestone or Cement Kiln Dust (CKD).

A list of wet scrubbing installations on cement kilns has been provided by MECS, Inc. For example, the DynaWave scrubber has been installed on a few cement plants in the U.S. including ESSROC Materials in Pennsylvania and Holcim in Michigan and Colorado. Subsequently we have learned, through a confidential informant, that the performance of these systems on long dry kilns has been questionable and that at least in one case the scrubber has been bypassed and replaced with a baghouse. Some of the criticisms included wet stack plume and high maintenance due to equipment corrosion.

A list of the most suitable documents is shown in Table 5.

The following provides a description of the technologies proposed by the four vendors that supplied budgetary quotations:

Manufacturer B

The proposed system would be installed after the existing baghouse for both the COGEN and kiln cases. The system employs standard limestone pebbles in a moving bed reactor to remove sulfur dioxide from boiler flue gases. In the process, hot gases from the boiler are passed through the reactor in which the gas contacts a bed of limestone granules that are covered with a thin film of water. Sulfur dioxide is absorbed from the flue gas into the water film where it subsequently reacts with the dissolved $CaCO_3$. A layer of reaction products precipitates onto the surface of the limestone as the reaction proceeds. The limestone and reaction products travel to the bottom of the reactor in a controlled flow. The material then exits the reactor and the product is segregated from the limestone. The regenerated limestone is directed back to the top of the reactor for reuse. The proposal includes the reactor, system fan, limestone regeneration screen, and all necessary material conveying equipment.

Manufacturer B

The proposed dry injection hydrated lime ($Ca(OH)_2$) system consists of an up flow circulating fluid bed reactor, a hydrated lime injection, lime storage silo, pulse jet baghouse, baghouse bypass gas reheat, and system fan. The system would be installed after the air preheater for the COGEN and after the economizer for the kiln case.

Manufacturer D

Manufacturer D proposes to use sodium bicarbonate injection into their proprietary venturi reactor. The reactor would be installed upstream of the existing Ecolaire baghouse (Manufacturer D only responded to the COGEN RFP) and the proposal assumes the baghouse is in good working order. The reactor would provide the sufficient residence time for the reagent to have the required intimate contact with the acid gas. The partially spent reagent and reaction products would be captured in the existing baghouse and disposed of with the fly ash.

Manufacturer A

The Manufacturer A system employs dry hydrated lime as the reactant. The system consists of five major components; reaction tower, distribution venturi, fabric filter, recirculation system and fresh reagent storage/delivery system. In this technology process gases enter into the reaction tower near the bottom and flow upward to the distribution venturi at the base of the tower. The gas turns upward and is accelerated thru the venturi throat. The new and recycled reagent is mixed with the gas stream at a point above the venturi throat. New reagent is pneumatically conveyed from the storage silo to the reaction tower. From the tower the gases are directed to the baghouse, and the collected material is either recycled to the process or disposed of. This technology would be located after the air preheater for the COGEN and after the economizer for the kiln case.

Manufacturer C

The proposal offered by Manufacturer C employs a wet scrubber using a 20 % NaOH solution as the scrubbing reagent. The feed gas enters the top of a vertical duct and collides with the scrubbing liquid that is injected upward through a large bore injector or Reverse Jet Nozzle. The Reverse Jet nozzle is a very large bore, open throat nozzle that creates a full cone liquid flow that is essential to producing the required Froth Zone. The Froth Zone creates a very high rate of liquid surface renewal and efficiently quenches the gas to the adiabatic saturation temperature and absorbs the SO_2. After contacting, the gas-liquid mixture enters a separation vessel where the liquid drops to the sump of the vessel and the gas travel upward through the vessel. The collected liquid is recycled back to the circulation pump and flows to the Reverse Jet Nozzles. The system would be installed after the existing baghouses for both the COGEN and the cement cases.

Best Available Retrofit Control Technology (BARCT)

ETS has conducted a top down analysis of alternative commercially feasible control technologies for the control of SO_x emissions from the cement plant. This analysis considered the technology which was found to be the most effective in terms of sulfur dioxide removal and which can potentially be installed or retrofitted at CPCC.

Three vendors (Manufacturer A, Manufacturer B, and Manufacturer C) submitted quotes and performance claims. Manufacturer A proposed a dry fluid bed scrubber in conjunction with a baghouse and hydrated lime reagent achieving 90% removal efficiency. Manufacturer B also quoted a dry fluid bed scrubber & hydrated lime reagent with a 90% efficiency. In addition Manufacturer B also quoted a dry scrubbing moving bed employing limestone reagent capable of 95% efficiency. Manufacturer C proposed a wet scrubber with sodium hydroxide as the reagent with a outlet gas having less than 10 ppm of SO_2 (See Section V. E. of the Confidential Appendix for a vendor proposal comparison).

Given the higher removal efficiency (95%), the Manufacturer B Scrubber was selected as BARCT for the kilns.

Other environmental and cross-media impacts from the Manufacturer B scrubber for the cement kilns include utility usage, water, and solid waste treatment or disposal. For two scrubbers the combined annual quantities of each item are estimated as follows: Electricity, 8.5 million kWh; water consumption, 40 million gal.; cooling water, 140 million gal.; wastewater, 52 million gal.; compressed air, 400,000 scf; and solid waste disposal, 908 tons.

Similarly top down analysis was done for the coal-fired fluidized bed boiler emission control at the cement plant.

Four vendors (Manufacturer A, Manufacturer B, Manufacturer C, and Manufacturer D) submitted quotes and performance claims. Manufacturer D proposed a dry injection system utilizing a venturi reactor and sodium bicarbonate reagent achieving 95% removal efficiency. Manufacturer A proposed a dry fluid bed scrubber, utilizing hydrated lime reagent, followed by a baghouse achieving 90% removal. Manufacturer B proposed two systems; a hydrated lime fluid bed scrubber followed by a baghouse with 78% removal efficiency and also separately quoted a limestone moving bed scrubber with 95% removal. Manufacturer C proposed a wet scrubber with sodium hydroxide as the reagent with a outlet gas having less than 10 ppm of SO_2 (See Section V. F. of the Confidential Appendix for a vendor proposal comparison).

Given the 95% removal efficiency, both the Manufacturer D Venturi Reactor & the Manufacturer B Scrubber can be considered BARCT for the coal-fired fluidized bed boiler.

While the quotes included "performance guarantees" it should be noted that these were budgetary quotes and we would expect the final quotes to have the guarantees tied to specific operating conditions and ranges. In addition there is the need to rigorously examine the installation list of these vendors and possibly visit some reference sites to verify good long term operation.

In the case of the coal-fired fluidized bed boiler control, the BARCT choice of the Manufacturer D system versus the Manufacturer B scrubber will be driven by cost considerations. It appears that these would favor Manufacturer D if only capital cost were considered, however, the higher reagent cost as well as the disposal of the reaction product need further analysis.

Other environmental and cross-media impacts from the Manufacturer B scrubber for the coal-fired fluidized bed boiler include utility usage, water, and solid waste treatment or disposal. Included are annual quantities of electricity, 1.0 million kWh; water, 10 million gal.; wastewater, 13 million gal.; cooling water, 35 million gal.; compressed air, 100,000 scf; and solid waste treatment, 550 tons.

In considering a curve of cost-effectiveness versus level of control there are two considerations. Firstly, will the control device capital cost vary with improved efficiency and secondly, will the operating cost increase with increasing efficiency. Since the capital cost is driven largely by the gas volume and since the volume is essentially constant there is little if any change in the capital cost over the considered range of efficiencies. With respect to operating cost versus efficiency, in the case of limestone, while the utilization does increase with increasing efficiency, the cost of the limestone was low enough to minimize the impact of efficiency on cost. Thus the merit of plotting a curve of cost versus efficiency seemed of little value.

III. D. Identification of Relevant Vendors and Contact Status

ETS has completed a top-down analysis, starting with the commercially viable control technology that is most effective and can be potentially installed or retrofitted at CPCC.

In addition to in-house resources and personal contacts within the air pollution control industry, ETS contacted both the Institute of Clean Air Companies (ICAC) and the Council of Industrial Boilers Association (CIBA) for assistance in identifying suitable FGD equipment suppliers. These vendors were contacted and supplied with a request for a technical response to the RFP's shown in Table 6 and 7. The vendors were asked to provide a Budgetary Equipment Cost and Estimated Annual Operating cost at the following three levels of performance:

1) Lowest achievable level of efficiency with guarantee
2) Next lowest achievable level of efficiency with guarantee
3) Most comfortable achievable efficiency with guarantee

The purpose of the RFP's was to eliminate the non-responsive or those with technical limitations (when considering the site specific demands at CPCC), thus, establishing a list of viable vendors, their technical approach, and the level of SO_2 removal they would guarantee.

Of the 16 vendors supplied with the proposal request, to date, only four (4) have provided a response. In general, the vendors questioned the low SO_2 levels, stating that 200-400 ppm was more typical of long dry kiln operations. Several also indicated that before guaranteeing performance level, they would require pilot testing to confirm design information and to optimize operational parameters.

Please refer to the Confidential Appendix (Section V. G.) for a list of the specific comments received by the vendors. The list of vendors, contact person and comments on the status of their proposal efforts is shown in Section V. H. of the Confidential Appendix.

IV. COST ANALYSIS

IV. A. Approach and Basis for Equipment Sizing and Cost Estimates

The approach to developing the cost estimates initiated with contacting FGD equipment vendors for their inputs on performance, capital and expected operating costs. The request of vendors for a technical response mentioned in Section III.C of the report was the first step in this process. The intent was to compare the estimated costs of installing new equipment with those costs of modifying existing equipment.

For each technology approach we began by preparing a Discounted Cash Flow (DCF) cost analysis. The DCF approach determines the value of a project using the time value of money by estimating all future cash flows and discounting them to determine the equivalent present value cost. For consistency with other AQMD rule development projects and Air Quality Management Plant (AQMP), present value (or present worth value, PWV) was estimated with the following equation:

$$PWV = C + (CF_1 \times A) - (CF_1 \times S) + SUM\ (CF_{2,n} \times F_n)$$

Where:

C = Capital cost, $, a single payment

A = Annual cost, $/yr, a series of uniform payments

S = Annual savings, $/yr, a series of uniform negative payments

F = Future cost, $, a single payment in a future year

CF_1 = Conversion factor from compound interest tables of the formula

$[(1 + i)^n – 1]/[i \times (1 + i)^n]$ where i = fractional interest rate and n = the nth year from the beginning. Used with a series of uniform payments from 1 to n.

$CF_{2, n}$ = Conversion factor from compound interest tables of the formula $1/(1 + i)^n$. Used with a single payment at any year n.

To be consistent with AQMD cost-effectiveness analysis, a 4% annual interest rate was used in the calculations.

The DCF included all anticipated capital and expense costs associated with the project or measure evaluated. The capital portion of those costs included materials, labor, and other directs, as well as engineering, management, taxes, shipping, and various indirect costs incurred for the particular control technology. Every cost item incorporated in the estimate was site and equipment specific. Wherever possible, cost elements were individually listed, quantified, and costed via the use of applicable unit rates. In that fashion (i.e., “line-item” estimating, in lieu of purely factored costs), the relative precision of the overall estimate was optimized. Also, reviewers of the cost development sheets had the greatest insights into how the estimates were assembled; they were then more easily able to adjust the results to reflect scope changes or improved data.

The DCF for a given technology also took into account the forecasted operating cost increments--plus revenues, if any--over the expected lifetime of that package. Such costs included utility, waste, operating, maintenance, and other impacts.

Whenever possible vendor/manufacturer budgetary quotes and local material/labor costs were used in our estimates. When these costs were not available, ETS’ standard cost estimating methodologies for material and labor were used to complete the pricing exercises.

IV. B. Equipment Cost Information

A short list of vendors was identified and they were asked to provide a budgetary cost estimate for the supply and installation of their equipment. The vendor was also requested to identify any utilities needed and their expected rate of usage. The vendor was also asked to identify the amount and type of waste generated by the process. If the vendor’s approach was to modify or retrofit existing hardware, he was requested to supply a cost estimate for those activities. For example, if the proposed approach was that of dry or wet injection upstream of the baghouse, the proposal should have included an estimate for all required equipment hardware, reagent storage vessels, reagent feed control instrumentation, engineering, construction and installation, etc., as well as pre-engineering costs such as site testing activities to locate the reagent injection site to optimize system performance with respect to SO_2 control and reagent utilization.

IV. C. Annual Operating Costs and Cost-Effectiveness Analysis

Operating costs were developed for each of the short-listed approaches. In conducting this exercise we evaluated (and modified as needed) vendor-supplied information such as utility usage, system pressure loss, waste stream rates, etc. and input them into our costing calculations. Among the analytical methods used were those described by Vatavuk in his text; "Estimating Cost of Air Pollution Control" and the "EPA Air Pollution Control Manual". These methods have traditionally used an annualized cash flow for cost-effectiveness analysis; however for this program we used a Discounted Cash Flow method at a 4% real interest rate and 7.5% tax. Labor costs were developed using rates identified in the government labor rate website. The cost-effectiveness analysis also included an evaluation of the technology's potential for reducing multiple pollutants, if any, that exist concurrently over the same useful life of the control equipment.

AQMD requires comparative cost and cost-effectiveness information for control of SO_2 at several concentrations and with several types of control systems. This information was used to determine economic and regulatory reasonableness of requiring any of the various control combinations. Equipment vendors furnished cost estimates for systems they can supply. Elements of the cost included, either by the vendor or by contractor personnel, categories such as foundations; structural steel; equipment; duct, piping and mechanicals; electrical and controls; waste disposal; miscellaneous; and contingencies. Each category was further divided into materials and equipment, labor, and other costs. As complete sets of costs were collected for each concentration and equipment type, a spreadsheet program was used to analyze the data. The discounted cash flow method, as described above, was used to arrive at present worth value. Cost-effectiveness of the equipment type/SO_2 reduction quantity (mass of SO_2 removed from a plant's emission stream over the life of the control) was estimated in $/ton of pollutant removed by dividing PWV by the mass of SO_2 removed.

A cost-effectiveness determination was executed for the BARCT case and a summary of the results are provided in Table 8.

IV. D. Inputs for Cost Estimation Modeling

A spreadsheet model uses case-specific vendor quotes for major equipment systems and for some elements of installation, operation , and maintenance. These quotes may include materials, labor hours, and utilities. Where information is not available from the major equipment vendors of a control system supplying the base quote, other vendors may be contacted for estimates of smaller pieces of equipment, supplies, and construction work. If such contacts are not productive, literature sources may be sought for current costs and estimates of operating labor, materials, supplies, and utilities.

The model used for this work allows for inputs from all these categories. The input section of the model provides a series of cells that, under the heading of structural steel for example, allow for primary, secondary, and platform steel in tons or square feet. Unit costs are obtained and applied to the steel quantities for a total cost for steel not included in equipment quotes. Further, unit times for erecting the steel (labor hours per ton) can be estimated for specific jobs or obtained from sources such as R.S. Means construction cost manuals. Total labor cost for erection is number of tons of steel times the unit cost of labor. If other costs such as buying a prefabricated storage shed installed at the job site are needed, they can be entered into the model. All costs within the category of structural steel are summed, and the remaining categories are also summed and added together to estimate a total equipment and installation cost. Table 9 shows the major categories within the model.

To provide a convenient means of handling labor and utility costs that are used across categories, separate spreadsheet tabs are constructed for storing these data. As changes occur to, for example, the cost of electricity or the cost of an electrician, new costs are entered into the data tabs and referenced by the main model tab.

Similarly to the equipment installation, ongoing operation and maintenance sections of the model apply unit costs to expected quantities of materials and labor to keep the equipment going. Space is provided for estimating ongoing costs annually, both constant costs and periodic costs such as major scheduled maintenance at five-year intervals. These costs are calculated on a line-by-line basis that can be used for financial estimates and for visual examination of changes in costs. Although not used for the AQMD work, the model can estimate costs with assumed annual escalation rates for labor categories, materials, supplies, and utilities. The model can also begin costing up to four years before startup, with capital expenditures apportioned as annual percentages for each year (see Table 10).

Cost-effectiveness over the control system life is found by dividing present worth value (PWV), described elsewhere in this report, by total tons of emission reduction. The model contains cells that collect values for the PWV equation terms, and adds those terms for a total PWV. Cells are also provided for baseline emissions taken from plant records of stack tests or CEM data. Design efficiency for the control system is applied to the baseline emission rate for an emission reduction (tons), which is the denominator in the equation for finding cost-effectiveness.

For a list of assumptions/information that ETS used in the cost analyses for the cement kilns and boiler, please see Table 11.

Table 1. CEMS Data for Kilns 1 & 2 and COGEN Plant

Statistic	CO2 (ppm)	CO (ppm)	CO rate (lb/hr)	NOx (ppm)	NOx rate (lb/hr)	O2 Dry (lb/hr)	O2 Wet (lb/hr)	SOx (ppm)	SOx rate (lb/hr)	Stack Delta Press (in H_2O)	Stack Flow (mdscfh)	Stack Temp (^oF)
2008 Kiln 1												
Count, non-zero	9,996	9,419	1,656	9,852	9,679	9,997	9,997	9,987	9,762	18,577	9,839	18,591
Max	18.83	4,981.96	1312	1,018.9	701.4	21.40	20.83	451.68	547.30	0.944	9,074	349.5
Min	0.02	0.01	1	19.7	4.3	2.50	2.50	1.06	0.22	0.0001	1,202	44.7
Average	13.50	264.32	121.14	153.74	121.67	12.29	11.31	8.93	9.71	0.12	6,685.43	182.84
Stdev	2.64	292.89	145.02	99.37	72.78	1.50	1.34	25.97	27.84	0.083	787.17	97.23
Relative std	0.196	1.108	1.197	0.646	0.598	0.122	0.118	2.909	2.867	0.689	0.118	0.532
2008 Kiln 2												
Count, non-zero	6,837	6,749	6,505	6,702	6,450	6,856	6,856	6,856	6,599	18,532	6,604	13,585
Max	18.93	5,023.13	2,079.00	999.98	525.44	21.19	20.73	273.39	354.48	1.00	9,242.56	436.29
Min	0.00	0.05	1	15.54	1.64	2.50	2.50	1.04	0.12	0.0001	686.81	0.04
Average	12.74	262.45	109.81	123.14	87.92	12.28	11.33	5.40	5.56	0.06	6,011.43	153.78
Stdev	2.79	320.40	113.75	70.54	48.30	1.74	1.79	17.32	18.09	0.06	1,242.68	130.88
Relative std	0.219	1.221	1.036	0.573	0.549	0.142	0.158	3.211	3.251	1.103	0.207	0.851
2005 Kiln 1												
Count, non-zero	8,657	8,549	8,551	8,524	8,569	8,517	8,517	8,517	8,569		8,515	8,742
Max	17.46	2,290.74	1,176.43	815.28	706.02	19.69	18.42	167.58	352.08		10,936.47	362.71
Min	0.0032	0.14	0.08	100.00	56.17	1.98	5.99	1.13	0.89		3,878.35	17.11
Average	14.18	257.39	137.58	128.75	113.98	12.23	11.34	4.40	6.31		7,380.30	259.55
Stdev	1.48	163.70	87.81	42.47	38.81	0.63	0.55	7.27	16.76		387.90	26.04
Relative std	0.104	0.636	0.638	0.330	0.340	0.052	0.048	1.652	2.656		0.053	0.100
2005 Kiln 2												
Count, non-zero	8,632	8,417	8,424	8,411	8,449	8,405	8,405	8,411	8,449		8,411	8,739
Max	17.39	2,351.05	1,344.49	763.25	722.40	20.88	20.50	373.15	492.35		10,537	360
Min	0.0016	0.01	0.00	100.00	37.54	1.89	4.87	1.13	0.54		2,864	8.33
Average	12.17	269.12	146.87	126.08	114.10	13.50	12.35	12.34	16.69		7,590	309.55
Stdev	1.76	222.04	119.74	41.93	40.07	0.94	0.96	23.86	34.89		485.40	43.93
Relative std	0.145	0.825	0.815	0.333	0.351	0.070	0.078	1.934	2.091		0.064	0.142

Table 1 (Continued)

Statistic	CO2 (ppm)	CO (ppm)	CO rate (lb/hr)	NOx (ppm)	NOx rate (lb/hr)	O2 Dry (lb/hr)	O2 Wet (lb/hr)	SOx (ppm)	SOx rate (lb/hr)	Stack Delta Press (in H_2O)	Stack Flow (mdscfh)	Stack Temp (^{o} F)
2001 COGEN												
Count, non-zero	5,816	4,519	4,494	4,467	4,566	4,483	4,483	4,457	4,592		4,457	5,669
Max	22	15,255	2,867	470	337	22	21	188	149		6,753	334
Min	0.000	0.751	0.002	0.808	0.031	2.194	1.698	1.000	0.004		940	18.0
Average	14.34	70.86	12.61	239.96	74.31	5.49	4.86	97.39	40.79		2,554	229
Stdev	2.83	442.98	90.44	110.45	39.66	2.73	2.62	56.11	24.73		416	86.0
Relative std	0.197	6.251	7.174	0.460	0.534	0.497	0.540	0.576	0.606		0.163	0.376

Notes to Table 1, Cement Kiln Statistics - all supplied variables

Note 1. Only non-zero numerical values used, total rows = 8,760 (2005, both kilns), 18,909 (2008, both kilns), 5,825 (2001-2002 COGEN)
Note 2. Hourly and quarter-hourly data not treated separately
Note 3. SO_2 data for 2008 have many repeats of 1.06099999 ppm for kiln 1 and 1.043000 for kiln 2.
To a lesser extent the 2005 data have repeats of 1.13400 (kiln 1) and 1.12800 (kiln 2). COGEN data had repeats for 170.744751 and 187.682607.
Note 4. NOx data also have repeat strings, at least for '05 and COGEN data

Table 2. Kiln #1 - SO2, Temperature, and Flow Rate Information

			Kiln #1 - SO_2 , Temperature and Flowrate Information									
Data Source	**Average SO_2 (ppm)**	**Max. SO_2 (ppm)**	**Average SO_2 Rate (lb/hr)**	**Max. SO_2 Rate (lb/hr)**	**Average SO_2 Rate (tons/day)**	**Max. SO_2 Rate (tons/day)**	**Average Stack Temp. (° F)**	**Max. Stack Temp. (° F)**	**Average Stack Flow (mdscfh)**	**Max. Stack Flow (mdscfh)**	**Average Stack Flow (dscfm)**	**Calculated Stack Flow (acfm)**
2005 CEMS (Jan.-Dec.)	4.40	168	6.31	352	0.076	4.22	260	363	7380	10936	123,000	172,262
2008 CEMS (Jan.-Sept.)	8.93	452	9.71	547	0.117	6.56	270	350	6685	9839	111,417	158,207
Site Visit 9/18/08 Control Room Snapshot	94.8 *Probably Spiked-RATA		115.57 *Probably Spiked-RATA		1.38 *Probably Spiked-RATA		274		7336		122,267	174,565
SO_2 ppm Calculation	8.6				0.129 *Used highest # from draft		274					175,000
Waters System (e-mail from Minh)	2 - 65				0.01 - 0.75							
NESHAP (January 2007) **Waste Heat Boiler Bypassed - Extreme Conditions**							No data				130,748	
Rule 1156 (October 2007)							No data				110,856	
RATA (June 2005) Normal Operation							271		6006		100,100	142,332
RATA (May 2005) **Waste Heat Boiler Bypassed - Extreme Conditions**							357		8298		138,300	219,784
Note 1:Used 3% moisture for ACFM calculation												
Note 2: No correction for pressure in ACFM calculation (no data)												

Table 3. Kiln #2 - SO2, Temperature, and Flow Rate Information

			Kiln #2 - SO_2 , Temperature and Flowrate Information									
Data Source	**Average SO_2 (ppm)**	**Max. SO_2 (ppm)**	**Average SO_2 Rate (lb/hr)**	**Max. SO_2 Rate (lb/hr)**	**Average SO_2 Rate (tons/day)**	**Max. SO_2 Rate (tons/day)**	**Average Stack Temp. (° F)**	**Max. Stack Temp. (° F)**	**Average Stack Flow (mdscfh)**	**Max. Stack Flow (mdscfh)**	**Average Stack Flow (dscfm)**	**Calculated Stack Flow (acfm)**
2005 CEMS (Jan.-Dec.)	12.34	373	16.69	492	0.200	5.90	310	360	7590	10537	126,500	189,467
2008 CEMS (Jan.-Sept.)	5.40	273	5.56	354	0.067	4.25	279	436	6011	9243	100,183	144,010
Site Visit 9/18/08 Control Room Snapshot	1.04		0.87		0.010		271		5006		83,433	118,634
SO_2 ppm Calculation	18.7				0.193 *Used highest # from draft		271					120,000
Waters System (e-mail from Minh)	2 - 65				0.01 - 0.75							
NESHAP (January 2007) **Waste Heat Boiler Bypassed - Extreme Conditions**							No data				124,716	
Rule 1156 (October 2007)							No data				108,200	
RATA (June 2005) Normal Operation	RATA only performed on Kiln # 1											
RATA (May 2005) **Waste Heat Boiler Bypassed - Extreme Conditions**	RATA only performed on Kiln # 1											
Note 1:Used 3% moisture for ACFM calculation												
Note 2: No correction for pressure in ACFM calculation (no data)												

Table 4. COGEN - SO2, Temperature, and Flow Rate Information

			COGEN - SO_2 , Temperature and Flowrate Information										
Data Source	**Average SO_2 (ppm)**	**Max. SO_2 (ppm)**	**Average SO_2 Rate (lb/hr)**	**Max. SO_2 Rate (lb/hr)**	**Average SO_2 Rate (tons/day)**	**Max. SO_2 Rate (tons/day)**	**Average Stack Temp. (° F)**	**Max. Stack Temp. (° F)**	**Average Stack Flow (mdscfh)**	**Max. Stack Flow (mdscfh)**	**Average Stack Flow (dscfm)**	**Calculated Stack Flow (acfm)**
2001 CEMS (Aug. 2001-Mar. 2002)	97.4	188	40.79	149	0.489	1.79	270	334	2554	6753	42,567	60,443
CPCC Data (July 2001-March 2002)			31.83	86.67	0.382	1.04			2459	6016	40,983	
Source Test 3/21/2002 (e-mail from AQMD)	82		38		0.456							
SO_2 ppm Calculation	87.3				0.456 *Used 3/21/02 source test		270					60,443
Note 1:Used 3% moisture for ACFM calculation												
Note 2: No correction for pressure in ACFM calculation (no data)												

Table 5. List of Reference Documents for Cement Industry

AQMD, 2008. *South Coast Air Quality Management District – Preliminary Draft Staff Report SO_x RECLAIM Part I Allocations, Emissions & Control Technologies,* April 2008.

CARB, 1978. *Feasibility of Installing Sulfur Dioxide Scrubbers on Stationary Sources in the South Coast Air Basin of California*. Prepared by P.P. Leo and J. Rossoff of The Aerospace Corporation for California Air Resources Boad, Contract No. A6-211-30, August 1978.

EPA, 2007. *The U.S. Environmental Protection Agency RACT/BACT/LAER Clearinghouse,* 2007. http://cfpub.epa.gov/rblc

LADCO, 2005. *Midwest Regional Planning Organization – Identification and Evaluation of Candidate Control Measures*, MACTEC Federal Programs, Inc. developed for Lake Michigan Air Directors Consortium (LADCO), April 14, 2005.

LANEY, 2005. Memorandum – *Summary of Environmental and Cost Impacts of Proposed Revisions to Portland Cement NESHAP*, Prepared by Mike Laney and David Green of RTI to Keith Barnett MICG/ESD/OAQPS/EPA, August 19, 2005.

MILLER, F.M., Young, G.L., and von Seebach, M., *Formation and Techniques for Control of Sulfur Dioxide and Other Sulfur Compounds in Portland Cement Kiln Systems,* R&D Serial No. 2460, Portland Cement Association, Skokie, Illinois, USA, 2001, 56 pages.

NESCAUM, 2005. *Assessment of Control Technology Options for BART-Eligible Sources – Steam Electric Boilers, Industrial Boilers, Cement Plants, and Paper and Pulp Facilities.* Northeast States for Coordinated Air Use Management (NESCAUM) in partnership with the Mid-Atlantic Northeast Visibility Union (MANE-VU), March 2005.

NESCAUM, 2007. *Five-Factor Analysis of BARCT Eligible Sources – Survey of Options for Conducting BART Determinations.* Prepared by Northeast States for Coordinated Air Use Management (NESCAUM) for the Mid-Atlantic Northeast Visibility Union (MANE-VU), June,1 2007.

PCA, 1996. *U.S. and Canadian Portland Cement Industry: Plant Information Summary,* Portland Cement Association, December 31, 1996.

PECHAN, 2005. *Update of Control Equipment Data to Support Minnesota Pollution Control Agency (MPCA) Control Equipment Rule – Final Report,* Stephen M. Roe, Ying K. Hsu, Maggie Ma, Holly C. Linquist, E.H. Pechan & Associates, Inc., Report No. 05.06.00X/9446.000 CFMS No. A72995, June 2005.

RICHARDS, John, *Capabilities and Limitations of Available Control Techniques for Mercury Emissions from Cement Kilns,* R&D Serial No. 2748a, Portland Cement Association, Skokie, Illinois, USA, 2005, 49 pages.

Table 5 (Continued)

ROCK, 1995. *The 1996 North American Cement Directory*, Rock Products, 1995.

TRINITY Consultants, 2007. *BART Five Factor Analysis - Ash Grove Cement, Montana City, Montana.* Prepared by Trinity Consultants, June 2007.

Table 6. Request for Proposal (RFP) – Cement Kilns

FGD Vendor (Cement) Preliminary Technical RFP

The Project

The facility operates two "long dry process" rotary kilns; each kiln is about 13 ft. in diameter bottling out to 15 ft. by 490 ft. in length. The operation for each kiln is as follows; raw materials are fed into the upper end of the kiln while fuels are burned at the lower end. The combustion fuel is a combination of coal, coke, oil, natural gas, and used tires. Raw feed material consists of limestone, silica, and clay. As the kiln rotates, the raw materials and combustion gases flow in a countercurrent direction. The combustion gases are vented through an economizer. The gases are then directed to a reverse gas baghouse before exiting through the exhaust stack. The material captured in the baghouse can either be reused as feed or targeted for waste disposal. A simple line diagram typical of each kiln operation is attached as Figure 1. Flue gas ranges (typical for each kiln and taken at the stack) to be used for FGD design are as follows:

Parameter	average / range
Gas Flow Rate (ACFM)	170,000 – 200,000
Gas Temperature (^{o}F)	275
Gas Composition	
O_2 Dry (%)	12
H_2O (%)	3
NO_x (ppm)	120 - 150
SO_2 (ppm)	5 - 25
Particulate (gr/scfd)	.003 - .005

Additional Design Information:

Energy Star Facility – Use premium efficiency motors
Earthquake 4 Zone
Elevation is 1000 ft. above sea level
Stainless Steel is required in any moisture situation

Your response should include the following technical information:

Process Type (examples; induct injection, spray drying, wet scrubbing)
Process Equipment (major equipment components and weights)
Equipment Footprint (rough dimensional outline)
Reagent Type
Reagent Usage Rate (estimate for min/max conditions)
Reagent Utilization (expected for min/max conditions)
Pressure Loss (across FGD process equipment)
Temperature Loss (across FGD equipment)
Utility Requirements
Cement Kiln Installations & References

Please quote the Budgetary Equipment Cost and Estimated Annual Operating Cost at the following three levels of performance:

1) **Lowest achievable level of efficiency with guarantee**
2) **Next lowest achievable level of efficiency with guarantee**
3) **Most comfortable achievable efficiency with guarantee**

Table 7. Request for Proposal (RFP) – COGEN Boiler

FGD Vendor (Fluidized Bed Boiler) Request for Budgetary Quote

The Project

The facility also has a Cogen plant that features a coal-fired fluidized bed boiler. The 18 MW boiler was supplied by PyroPower in 1985 and has not been operated since 2002. Future circumstances may dictate that the boiler may be operated in the near future and if so, SOx emissions will need further reduction from their previous levels (years 2001-2002). Particulate emissions are controlled by a pulse jet baghouse; the controls were considered BACT at the time the operation was permitted. A line diagram of the boiler system is presented in Figure 2. Flue gas parameters, taken at the stack, to be used for FGD design are as follows:

Parameter	
Gas Flow Rate (ACFM)	60,000
Gas Temperature (^oF)	300
SO_2 (ppm)	100

Additional Design Information:

- Energy Star Facility – Use premium efficiency motors
- Earthquake 4 Zone
- Elevation is 1000 ft. above sea level
- Stainless Steel is required in any moisture situation

Your response should include the following information:

- Process Type (examples; induct injection, spray drying, wet scrubbing)
- Process Equipment (major equipment components and weights)
- Equipment Footprint (rough dimensional outline)
- Reagent Type
- Reagent Usage Rate (estimate for min/max conditions)
- Reagent Utilization (expected for min/max conditions)
- Pressure Loss (across FGD process equipment)
- Temperature Loss (across FGD equipment)
- Utility Requirements
- Industrial Boiler Installations & References

Please quote the Budgetary Equipment Cost and Estimated Annual Operating Cost at the following three levels of performance:

1) **Lowest achievable level of efficiency with guarantee**
2) **Next lowest achievable level of efficiency with guarantee**
3) **Most comfortable achievable efficiency with guarantee**

Table 8. Cost-Effectiveness Table

Cement Plant SO_2 Control at 95 % Efficiency			
		Calcium Carbonate Scrubbers, 2 kilns	**Calcium Carbonate Scrubber, boiler**
Baseline Emissions	ton/yr	97.5	138.7
Emission Reduction	ton/yr	92.6	131.8
Equipment Cost	$ million	16.6	4.7
Annual Operating Cost	$ million	1.5	0.39
Capital Cost	$ million	19.6	6.1
Present Worth Value (25 -Year Life)	$ million	43.7	12.6
Cost-Effectiveness Factors			
SO_2 Reduction	$/ton	18,893	3,818
SO_2 + PM reduction	$/ton	N/A	N/A
Note: Baseline SOx emissions used in calculations were from 2005 (SCAQMD database for the period from January 2005 - December 2005)			

Table 9. Major Categories of Costing Model Inputs – Capital Costs

Demolition and Decommissioning
Civil/Concrete
Structural
Equipment
Piping & Mechanical
Electrical & Controls
<u>Misc. Direct & Indirect Costs</u>
Contractor overhead and misc. rentals
Contractor field supervision
Mobilization/Demobilization
Overtime/productivity factor
Freight/shipping
Sales Tax
Commissioning and operating spares
Start-up/initial fill material
On-site training/start-up assistance
FEED engineering through detailed design
Project management

Table 10. Major Categories of Operating and Maintenance Costs

<u>Annual Maintenance Costs</u>
<u>Periodic Maintenance Costs</u>
<u>Additional Operating Costs</u>
<u>Utilities</u>
Natural Gas
Electricity
Water
Wastewater
Cooling Water
Compressed Air
Solid Waste Disposal

Table 11. List of Assumptions for Cost Analysis

The following is a list of the assumptions/information that ETS used in the cost analyses for the kilns and boiler:

- Costing is for two scrubbers at one site based on one quote for a single scrubber
- Baseline emissions are taken from 2005 data estimating a rate of 0.267 tpd for the plant (kilns) and 0.38 tpd for the boiler
- Scrubber control efficiency: 95%
- Life of control equipment: 25 years
- Purchased equipment costs (with auxiliaries, instruments, freight, taxes): $16.6 million for the kiln scrubbers and $4.7 million for the boiler
- Control equipment vendor quotes based on 25 ppm SO_2 at scrubber inlet (0.31 tpd)
- Annual operating costs are $1.5 million for the kiln scrubbers and $0.4 million for the boiler
- Project management costs are based on 1 engineer for 3,000 hours and 1 manager for 2,000 hours for the kilns, and the same number of hours for the boiler. (Note: There may be a variation in these numbers depending on the application itself and the nature and size of the engineering company).
- Overhaul (turnaround) maintenance is performed every 5 years starting the fifth year after startup for both projects.
- Startup is 2 years after the project begins for both cases
- Construction labor costs are allocated as 35 percent in the first year of construction and 65 percent during the second year for both projects
- Labor rates in $/hr for construction are:
    1. Laborer 90
    2. Civil/concrete worker 90
    3. Structural/iron worker 95
    4. Painter 90
    5. Insulator 100
    6. Mechanical/machinist 105
    7. Vessel/boilermaker 110
    8. Piping/pipe fitter 95
    9. Electrical/electrician 110
    10. Instrumentation/electrician 110
- Utility rates in $/unit during construction are:
    - Natural gas, $7.50/MM Btu
    - Electricity, $0.070/k/wh
    - Water, $4,000/MM gal
    - Wastewater, $6,000/MM gal
    - Cooling water, $0.50/MM gal
    - Compressed air, $0.15/1,000 scf
    - Solid waste disposal, $100/ton

Table 11 (continued)

Limestone (calcium carbonate) is $10/ton, available on site
Capital expenditures for equipment purchase and construction are all made in the first year.
The spreadsheets for estimating PWV are adapted from a procedure that estimates net present value on a line-by-line (year–by-year) basis beginning a specified number of years before startup (1 to 4). Capital costs for equipment purchase and construction are included in the years preceding startup. This procedure estimates net present values that are different from AQMD's PWV.

Because of this difference the spreadsheet has modifications that use the line-item costs, but regroup them in a manner suitable for use in the PWV equation.

- Categorized costs include:
  - Demolition and decommissioning
  - Civil/concrete
  - Structure
  - Equipment
  - Piping and Mechanical
  - Electrical and controls
- Miscellaneous line items
  - Contractor overhead, 8 % of direct field labor (DFL)
  - Contractor field supervision, 12 % of DFL
  - Mobilization/demobilization, 10 % of DFL
  - Overtime/productivity factor, 12 % of DFL
  - Freight and shipping, included in equipment pricing
  - Sales tax, 7.5 % of materials
  - Commissioning and operating spares, 5 % of materials
  - Startup/initial fill material, 2 % of materials
  - On-site training/startup assistance, 2 % of materials
  - Front-end engineering design, 3,000 hrs
  - Project management, 2,000 hrs

Figure 1. Diagram of Cement Plant Kiln Process
Typical of Kilns 1 and 2

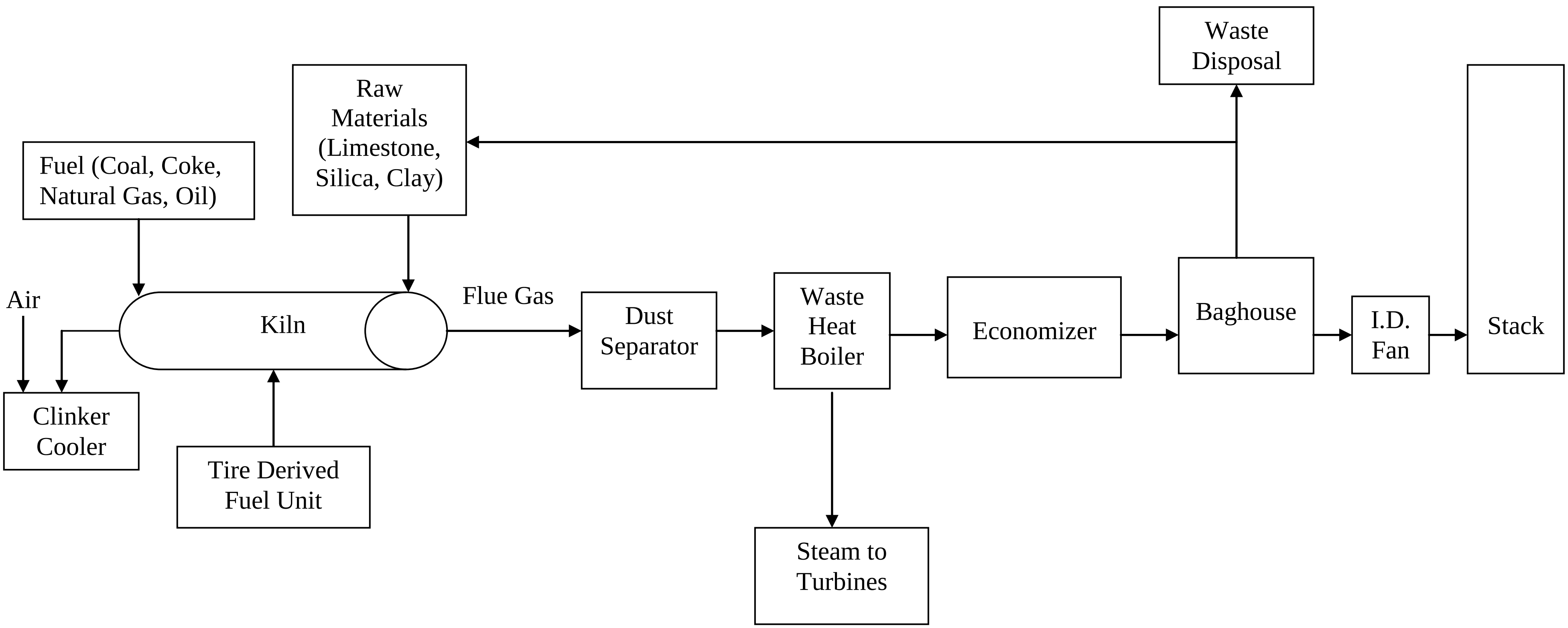

Figure 2. Diagram of Coal-Fired Fluidized Bed Boiler